

18 **ABSTRACT**

19 Clinical relevance

20 Peripheral vision is known to be critical for spatial navigation yet, visual cognition, has been the
21 object of few interests in glaucoma; a pathology that affects peripheral vision.

22 Background

23 Spatial memory was assessed with a paradigm developed by Intraub and Richardson (1989)
24 known to induce a robust memory distortion called “boundary extension” in which participants
25 erroneously remember seeing more of a scene than was present in the sensory input.

26 Methods

27 15 patients with glaucoma and 15 age matched normally sighted controls took part in the
28 experiment. Participants were shown 10 photographs of natural scenes randomly displayed for
29 0.5s or for 10s. Following each scene the participant was asked to draw it from memory.

30 Results

31 On average, boundary extension was larger, by 12%, for patients than for controls, but the
32 difference was significant for 4 photographs. Patients tended to add more space between the
33 object and the edges than there was between the objects and the border of the photograph. A
34 control experiment in which participants were asked to draw isolated objects without scene
35 context resulted in a significant reduction of the memory distortion in both groups but patients
36 still drew the objects smaller than controls.

37 Conclusion

38 The results suggest that the reduced field of view in glaucoma has an impact on spatial memory
39 for scenes and on perception of size.

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43 INTRODUCTION

44 Glaucoma is a progressive optic neuropathy characterized by irreversible retinal ganglion
45 cell and optic nerve fiber loss. Vision loss in glaucoma is classically described as loss of
46 peripheral vision. Indeed, people with advanced glaucoma have significantly reduced peripheral
47 vision as measured by visual field tests. Some patients with a greater amount of field loss report
48 difficulties seeing objects on one or both sides.¹ Bilateral glaucoma is associated with limitations
49 in driving, bumping into objects, slower walking, and falls.² Yet, very few patients describe their
50 perception of the world as vision through a black tunnel. Crabb et al.³ showed that 26% of the
51 patients are unaware of their vision loss.

52 With reduced peripheral vision, the ability to obtain information for navigation and
53 memory of scene views is different. This may lead to systematic distortions in spatial
54 representations. Experimental support for spatial distortions comes from a study showing that
55 simulated peripheral field loss in normally sighted participants led to systematic distortions in
56 remembered target locations in a virtual environment.⁴ This finding was extended to real
57 peripheral field loss due to retinitis pigmentosa. Patients reported distortions in spatial
58 representations which increased with decreasing field of view.⁵

59 In normal vision a paradigm was developed by Intraub and Richardson⁷ to investigate
60 scene representations. They presented normally sighted young people with photographs of
61 natural scenes for a limited presentation time and asked them to draw the scenes from memory.
62 They noticed a systematic error in the participants' drawings: people remembered having seen a
63 surrounding, unseen but highly likely layout, from beyond the camera's point of view. This
64 phenomenon was called the "boundary extension effect". Boundary extension is not limited to
65 drawing from memory. The same outcome was observed in recognition,⁸ matching⁹ and
66 adjustment tasks,¹⁰ with presentation times varying from 250ms to more than 10s⁹ and with

67 pictures of various sizes.¹¹ This “extrapolation” was interpreted as resulting from the activation
68 of a mental representation that includes memory for prior views of a similar scene as well as
69 anticipated continuation of the scene beyond the boundaries of the view.¹²

70 Does a restricted field of view affect the memory representation for scenes and, as a
71 consequence, impact the boundary extension effect? This issue was examined in normally
72 sighted young people with vision blocking goggles.¹³ Performance was compared in two
73 monocular tunnel vision conditions in which vision was restricted to 3 cm or to 0.6 cm, and a
74 binocular normal viewing condition. The results showed that scenes were remembered with
75 extended boundaries (by 30%) in all three conditions suggesting that artificial restriction of the
76 peripheral field had no effect on memory. However, in contrast to an artificial tunnel vision in
77 normally sighted people, patients with an ocular pathology lose their peripheral vision over
78 decades. It might be that they compensate their visual field loss by remembering scenes larger
79 than they are. As a consequence the boundary extension might be amplified in patients with
80 progressive peripheral field loss compared to normally sighted participants. The present study
81 assessed this issue in testing patients with advanced glaucoma. If a restricted field of view
82 produces memory distortions^{4,5} then patients should draw the scenes smaller than they were
83 presented and thus exhibit a larger boundary extension. However, an alternative possibility is
84 that, due to their peripheral vision loss, the patients perceive the objects smaller than they are.
85 Indeed, Legge et al.⁶ showed that artificial restriction of the visual field, to a narrow field of 8° in
86 normally sighted observers, impaired spatial location of a target but also judgments of the size of
87 unfamiliar rooms. To assess whether a larger boundary extension, observed in patients, results
88 from a distortion in the memory representation of scenes or from a distortion in the perception of
89 size a control experiment was conducted in which participants were asked to draw isolated
90 objects extracted from the scenes. The boundary extension effect is known to be specifically
91 related to memory for scenes. Intraub et al.^{14,15} compared performance for scenes and for

92 isolated objects extracted from the scenes. They found boundary extension only for the scene
93 version of images. If a larger boundary extension in patients resulted from a distortion in the
94 memory representation of scenes to compensate for the smaller field of view then it should not
95 be observed for isolated objects. If it resulted from a distortion in the perception of size then
96 isolated objects should also be perceived and drawn smaller than their representation on the
97 photos.

98

99 **METHODS**

100 *Participants*

101 *Glaucoma patients*

102 15 adults (9 females, age 58.7 ranging from 28 to 85) with stable (no progression on three successive visual
103 field tests in the last 2 years) bilateral primary open angle glaucoma were recruited from the department of
104 ophthalmology in the Lille's university hospital. To be included in the study, patients had to have a visual
105 acuity 0.2 LogMAR or better in each eye at the Monoyer scale, a score $\geq 25/30$ on the Mini-Mental State
106 Examination, indicating that there were no gross deficits in cognitive function, no other ocular disease than
107 glaucoma, no neurological disease and no medication affecting attention. All participants underwent SITA-
108 standard 30-2 perimetry using a Humphrey Visual Field Analyzer (HFA, Carl Zeiss Meditec, CA, USA)
109 and had visual field defects consistent with severe glaucoma at the Hodapp–Parrish–Anderson grading
110 scale with mean deviation (MD) worse than -12 dB. The ophthalmologist checked for each participant if
111 there was a complaint in terms of motor skills or if there was a difficulty in writing. The demographic
112 details and clinical data of the 15 patients are summarized in Table 1. The patients' visual fields are
113 displayed in Figure 1.

114

115 *Controls*

116 15 normally sighted people (10 females, age 59.1 ranging from 26 to 89) were included. They
117 were either a relative or a friend of patients. Controls had a full eye examination to ensure that
118 they had no ocular pathology. Their visual acuity and MMSE score are presented in Table 1.

119 Both patients and controls were tested monocularly on their eye with worse mean deviation to
120 Humphrey Visual field for patients with glaucoma and on their preferred eye for controls. The
121 study was approved by the local ethic committee (CPP Nord-Ouest IV). In accordance with the
122 tenets of the Declaration of Helsinki written informed consent was obtained from all participants.

123 No significant difference was found between patients and controls in terms of age (58.7 vs 59.1,
124 $t(14) = 0.068, p = 0.95$), MMSE score (patients : 28.3 vs controls: 28.6, $t(14) = 1.073, p = 0.30$)
125 or visual acuity (patients : 0.049 LogMar vs controls: 0.033 LogMar, $t(14) = 0.604, p = 0.56$).

126 As there were 30 participants divided in two groups in the main experiment, a post hoc power analysis was
127 conducted with the software G*Power (Faul, Erdfelder, Lang, & Buchner). It showed that the power of the
128 design was : Power (1- β err prob)= 0.84 ; $\alpha = .05$; Effect size $d = 0.94$.

129

130 [Table 1 and Figure 1 about here]

131 *Stimuli*

132

133 The main experiment used 10 colored photographs of natural scenes containing an object (Figure
134 2A). The photographs of scenes were provided by Helene Intraub (University of Delaware). The
135 angular size of the scenes was $35^\circ \times 28^\circ$ (105 x 80 cm) at a viewing distance of 150 cm. A
136 control experiment was performed with isolated objects. In each scene the main object was cut
137 and pasted on a white background. The stimuli are displayed in Figure 2B. The main object had
138 the same size in the isolated version as in the scene version.

139 *Equipment*

140
141 The scenes were randomly displayed on a large screen (130 cm vertically x 144 cm horizontally)
142 by a video projector (Optoma DX 733) connected to a laptop computer (Dell).

143

144 *Procedure*

145

146 Fifteen patients and 15 age-matched controls participated to the scene drawing task. Only 8
147 patients and 8 normally sighted controls accepted to participate to the control experiment with
148 isolated objects. Participants were tested in a dimly illuminated room with the light off and a
149 weak light coming from the edges of venetian blind of the window. In the main experiment
150 (scene drawing) the 10 photos of scenes were centrally and randomly presented on a black
151 background. Five images were randomly presented for 0.5 s and the 5 others for 10 s.

152 Participants were given 10 sheets of paper containing a black outline of a rectangle (20 x 16 cm).
153 Immediately after each scene presentation they were asked to draw the scene from memory,
154 within the rectangle. There was no time limit. Participants were instructed to draw the pictures in
155 as much detail as possible and to keep the layout of the picture and relative size of the object as
156 accurately as possible. They were told to consider the edges of the rectangle to be the edges of
157 the photograph they had seen on the screen and to draw the pictures accordingly. In the control
158 experiment the 10 photos of isolated objects were centrally and randomly presented for 10 sec
159 each. Participants were given 10 sheets of paper containing a black outline of a rectangle (20 cm
160 x 16 cm). They were asked to draw it within the black rectangle. As in the main experiment with
161 scenes there was no time limit and participants were instructed to keep the layout of the picture
162 and relative size of the object as accurately as possible. They were told to consider the edges of
163 the rectangle to be the edges of the photograph they had seen on the screen and to draw the

164 pictures accordingly. The duration of each experiment varied between 20 to 30 min depending
165 on the degree of details of the drawings performed by each participant.

166

167 [Figure 2 about here]

168

169 *Data analysis*

170 For each participant, and each photograph, the magnitude of the boundary extension was computed using
171 the following formula: $(\text{area object drawn} / \text{area of the object in the picture}) * 100$. The areas of the objects
172 (photograph and drawing) were measured in drawing a rectangle surrounding the object. The measure was
173 made manually for each drawing. We then measured the distance between the edge of the object (top,
174 bottom, left and right) and the outline contour of the rectangle.

175 The completion was also measured. The completion was defined by as a cropped object on
176 photograph made whole (i.e., more completed) on the drawing from memory (e.g., butterfly, bird
177 house, racquet, phone pole and fork; see Figure 2).

178 **RESULTS**

179 **1. Scene drawing**

180 *The boundary extension effect*

181 An ANOVA using the software Systat 8.0 (Systat Software, Inc. San Jose, California) was
182 conducted on the data. The factors were the group and the exposure time. Five objects were not
183 drawn: 2/10 by one patient and 1/10 by three other patients. That occurred only at the 0.5 s
184 exposure time. The results are presented in Figure 3 for each photograph and in Table 1 for each
185 participant.

186 Consistent with previous studies on normally sighted participants⁹ there was no significant
187 effect of the exposure duration of the photographs on the magnitude of the boundary extension
188 (0.5 s: 49.4% vs 10 s: 52.2% $F(1, 28) = 3.63, p = .067$, Cohen's $d = .14$). On average patients
189 tended to exhibit a larger boundary extension effect than controls. The objects drawn covered
190 44.7% of the surface for patients vs 57% for controls. Due to the large inter individual variability
191 (see Figure 3) the difference was not statistically significant ($F(1, 28) = 3, p = .09$, Cohen's $d =$
192 $.64$).

193 An analysis performed on each image showed that the boundary extension was
194 significantly larger for patients than for controls on 4 photos: panda, lantern, racquet and phone
195 pole (see Figure 3).

196 Object completion

197 On average the 5 objects that were cropped by the picture's boundaries (phone pole, racquet,
198 fork, butterfly and bird house) were significantly more completed (e.g., participants drew the
199 complete fork) by controls than by patients ($F(1, 8) = 7.35, p = .027$, Cohen's $d = 2.87$) see
200 Figure 4.

201 [Figure 3 about here]

202 [Figure 4 about here]

203 **2) Object drawing**

204 The results are presented in Figure 5 for each photograph and in Table 1 for each participant. On
205 average the object was drawn smaller by patients than by controls (51.05% vs 63.53%) but the
206 difference was not significant ($F(1, 14) = 2.13, p = 0.16$, Cohen's $d = .78$).

207 The comparison of the two versions of pictures (scenes and isolated objects), in the long
208 exposure time (10 s), showed a significant main effect of the version of image ($F(1, 42) = 48.4$,
209 $p < .001$, Cohen's $d = 2.02$) with a larger boundary extension in the scene version (patients:
210 45.7% and controls: 58.7%) than in the isolated object version (patients: 51.05% and controls:
211 63.53%) and a main effect of group $F(1, 36) = 6.36$, $p < .01$, Cohen's $d = .38$) with patients
212 drawing the pictures smaller than controls in both experiments. There was no interaction
213 between group and experiment.

214 [Figure 5 about here]

215 Correlations

216 No significant correlation was found between the magnitude of visual field defect and the
217 magnitude of boundary extension ($r = 0.147$).

218 **DISCUSSION**

219 Few studies have investigated the impact of glaucoma on cognitive functions like spatial
220 cognition and how patients perceive the world.¹⁶ The present study examined whether
221 progressive peripheral field loss due to glaucoma affects spatial memory for scenes using the
222 ubiquitous boundary extension effect.

223 The results showed that patients tended to add more space between the object and the
224 edges of the rectangle than there was between the object and the border of the photograph,
225 suggesting that, though very few people with glaucoma are aware of their reduced peripheral
226 vision,³ it does affect spatial representations. During a navigation task, a distortion in spatial
227 representation was also reported in patients with retinisis pigmentosa; a pathology that also
228 reduces peripheral vision.⁵ Lenoble et al.¹⁷ showed that patients with glaucoma over-estimated
229 the distance of objects in their peripersonal space.

230 In normally sighted people Intraub and Richardson⁷ described two components in the
231 boundary extension effect: 1) the increase in space between the main object and the edges of the
232 rectangle and 2) the completion of cropped objects and/or the addition of objects not present in
233 the photograph but likely to be found in the scene. In the present study the completion of
234 cropped objects, in the scene version, was higher in the control group than in the patient's group,
235 especially at short exposure time. A 0.5 s exposure time allows only 2 fixations. As there was no
236 gap between the fixation cross and the onset of the picture, it is likely that the first fixation was
237 exactly at the center of the image. The cropped part therefore appeared in the periphery. It might
238 be that parts of the objects were less visible by people with a peripheral scotoma when the
239 exposure duration did not allow exploration of the images. Moreover, it has been shown that
240 participants with glaucoma exhibit reduced visual exploration.^{18,19} A study in normally sighted
241 participants showed that impeding eye movements by having participants view room-sized
242 spatial layouts through small apertures (a field of view restricted to 3° of visual angle) made
243 subsequent retrieval of spatial memory slower and less accurate.²⁰

244 The control experiment showed that the isolated version of object was also drawn smaller
245 than their representation on the photos. Intraub et al.¹⁵ compared drawing performance when the
246 same objects were presented in the context of a scene and in isolation. Boundary extension was
247 observed for objects in scenes. When the same objects were presented on a blank background
248 performance varied as a function of picture view: close-ups (large objects) were remembered and
249 drawn as smaller and wide-angle views (small objects) were remembered and drawn as larger.
250 Consistent with these results, Figure 5 shows that smaller objects (panda, lantern and bird house)
251 were drawn larger whereas large objects (bench, house, butterfly, pole phone, racquet and fork)
252 were drawn smaller. The car was an exception. However, for all participants (patients and
253 controls) the space occupied by the object was smaller in the drawing than it was on the photo.
254 Intraub et al.¹⁵ used a large number of photos and an equal number of close-ups and wide angle

255 views. The small number of pictures and small number of wide angle views might explain why
256 the boundary extension was not totally suppressed in the present study. Nevertheless, the
257 comparison of the two experiments showed that the memory distortion was significantly larger
258 with scenes than with isolated objects in both groups of participants.

259 In a drawing task with normally sighted participants, Konkle & Oliva²¹ showed that the drawn
260 size of the object depends on the assumed size of the object in the world with small objects, like
261 a key, being drawn small and large objects, like a house, being drawn larger. In the present study
262 small objects were drawn larger and large objects were drawn smaller. This result is not
263 inconsistent with their study as they also showed that participants were sensitive to the amount of
264 space specified by a frame, drawing objects in such a way that a consistent ratio between the
265 object and the paper size was preserved over a range of different frame sizes. Nevertheless,
266 participants with glaucoma drew both isolated objects and objects in scene smaller than controls
267 consistent with Legge et al.⁶ who found that artificial peripheral field loss led to a deficit in the
268 estimation of room sizes. This was explained by a deficit in the encoding of spatial cues due to
269 restricted eye movements. Impaired visual exploration cannot completely account for the results
270 as small objects like the lantern or panda did not require visual exploration. Rather it might be
271 that the representation of size is affected in glaucoma.

272 There is evidence from animal studies and voxel-based morphometry techniques in
273 humans that damage of the optic nerve in glaucoma propagates by means of transneuronal
274 degeneration towards the visual cortex.^{22,23} There is also evidence that neurodegeneration in
275 glaucoma spreads beyond the primary visual cortex.²⁴ The primary visual cortex has widespread
276 connections to other areas in the brain, such as the hippocampus, involved in spatial memory.^{25,26}
277 Neuroimaging studies in healthy young observers have shown that the boundary extension
278 phenomenon is associated with a strong activation in the retrosplenial cortex and the
279 hippocampus.^{27,28} Interestingly, Frezzotti et al.²⁹ showed grey matter atrophy in cortical regions

280 involved in object (the lateral occipital complex) and scene (the parahippocampal place area)
281 recognition in patients with glaucoma. It might be that the alteration in size perception and
282 memory for scenes results from a functional deficit in the network involved in scene perception
283 in glaucoma.

284 In a previous study with simulated peripheral field loss in normally sighted participants
285 Intraub reported no significant difference in boundary extension between the conditions with
286 small and large monocular tunnel vision and normal binocular vision.¹³ The present study
287 showed that boundary extension was larger in patients with reduced peripheral vision than in
288 normally sighted people. Two main differences might explain this result: (1) the use of more
289 close-up views than Intraub.¹³ Other studies from that group showed that tight close-ups elicit the
290 greatest boundary extension compared to wide angle views;^{14,15} (2) people with glaucoma have
291 had years to functionally adapt to the gradual reduction of their visual field. It might be that
292 seeing smaller parts of real world scenes, though not being aware of it, has an impact on memory
293 for scenes and size. People with reduced visual field perceive and remember objects smaller than
294 they are.

295

296 **CONCLUSION AND LIMITATIONS**

297 This study shows that people with glaucoma exhibit larger boundary extension than controls
298 when asked to draw photographs of scenes from memory suggesting that they compensate their
299 reduced visual field by activating larger representations of scenes but the control experiment,
300 with isolated objects, showed that they also draw objects smaller than seen on the screen
301 suggesting that the perception of size is also affected. However, most of the objects were close
302 up views and it has been shown that observers have a tendency to draw these large objects
303 smaller than they appear.^{13,30} The difference between patients and controls might have been more
304 reliable with more images and wider angle views. Participants were tested under monocular

305 viewing condition on the most severely impaired eye. The spatial memory and the representation
306 of size might have been less distorted under binocular viewing condition.

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313

314 **Figure legends**

315 **Table 1.** Clinical and demographic data about patients and controls. MD = mean deviation in decibel. VF =
316 visual field. % BE = percentage of boundary extension, E1 = Experiment 1, E2 = Experiment 2.

317 **Table 2.** Percentage of completion of the cropped objects as a function of the exposure duration (0.5s vs
318 10s) and the group (patients vs controls).

319 **Figure 1.** Gray-scale plot from the Humphrey Visual Field (30-2) of the tested eye of the 15 patients. * =
320 patients 7 and 12 had a severe glaucoma that did not allow testing with a 30-2 perimetry. These two
321 patients were tested with a 10-2 visual field.

322

323 **Figure 2.** A: The 10 photographs of scene used in Experiment1. B: The 10 photographs of isolated objects
324 used in Experiment 2.

325

326 **Figure 3.** The boundary extension, in terms of percent object drawn (see formula in the result section) and
327 the standard errors (*= $p < .05$, **= $p < .02$) as a function of the image used in Experiment 1 and the group
328 (patients vs controls).

329

330 **Figure 4.** Examples of drawings from control participants and from patients with glaucoma.

331

332 **Figure 5.** Comparison of the boundary extension for Scene Drawing Experiments (top) and Object
333 Drawing Experiment (bottom), in terms of percent object drawn (see formula in the result section), and the
334 standard errors, as a function of the image and the group (patients vs controls).

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400

401 **Table 1**

PATIENTS	AGE	GENDER	TESTED EYE	ACUITY (LogMAR)	MMSE	MD (dB)	VF(degree)	%BE E1 scene	%BE E2 object
1	56	F	R	0.00	30	-21.29	12	58	76.5
2	83	F	L	0.10	25	-23.05	12	35	
3	37	M	R	0.00	27	-27.03	11	66	51.3
4	60	F	R	0.10	29	-15.67	12	32	62.2
5	68	M	R	0.00	28	-29.39	10	43	51.2
6	85	M	R	0.10	28	-24.00	10	36	61.9
7	46	M	R	0.00	30	-24.04	12	48	
8	52	F	R	0.00	26	-10.87	12	17	17.2
9	50	F	R	0.10	28	-16.31	11	47	35.9
10	39	M	L	0.00	30	-12.86	12	99	
11	83	F	L	0.10	27	-15.58	10	67	
12	64	F	L	0.20	30	-33.72	6	37	52.2
13	70	F	R	0.10	28	-15.55	12	47	
14	60	F	R	0.10	30	-17.70	10	17	
15	28	M	R	0.10	29	-22.76	12	36	
CONTROLS	AGE	GENDER	TESTED EYE	ACUITY (logMAR)	MMSE	%BE E1 scene	%BE E2 object		
1	32	M	R	0.00	30	68	76		
2	56	F	R	0.00	28	76			
3	79	F	R	0.10	28	75	75.1		
4	65	M	R	0.00	30	56	90.1		
5	54	F	R	0.00	30	82	51.6		
6	54	M	R	0.00	28	60	53.9		
7	41	M	R	0.00	30	69			
8	53	F	R	0.00	30	21	49.7		
9	65	F	R	0.00	28	33	67.8		
10	88	F	R	0.00	27	61			
11	26	M	R	0.00	30	66			
12	62	F	R	0.00	26	53	44.1		
13	45	F	R	0.00	29	66			
14	89	F	L	0.10	26	16			
15	78	M	R	0.00	30	58			

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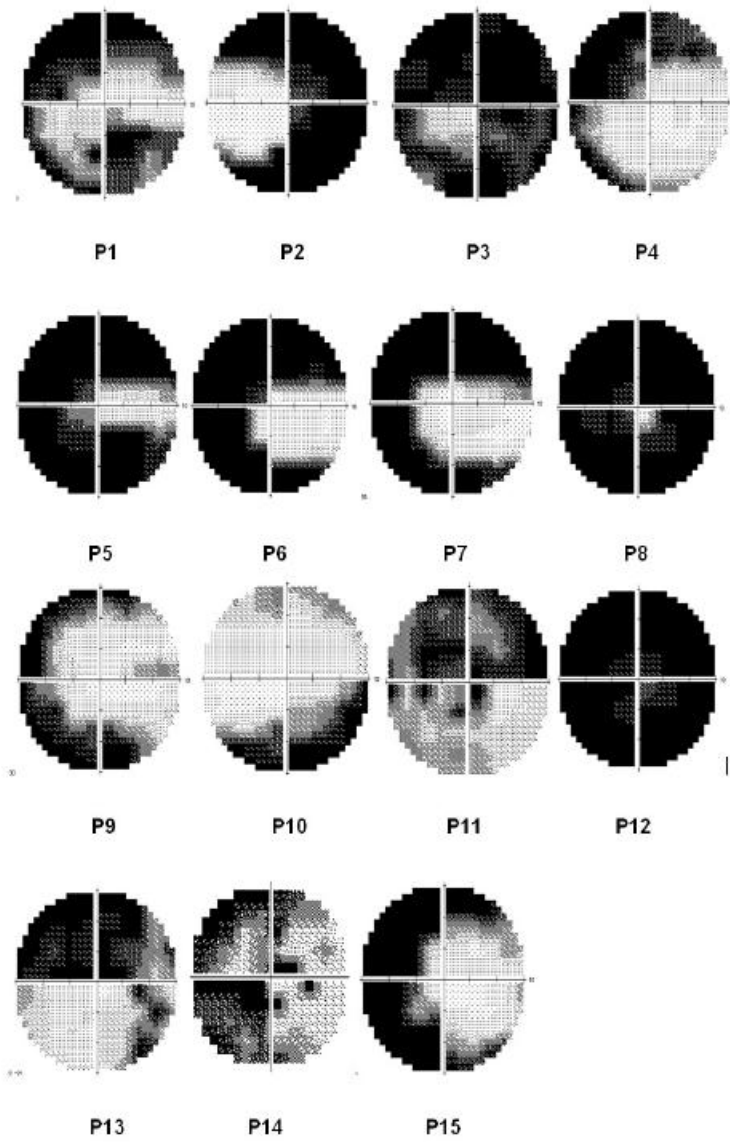
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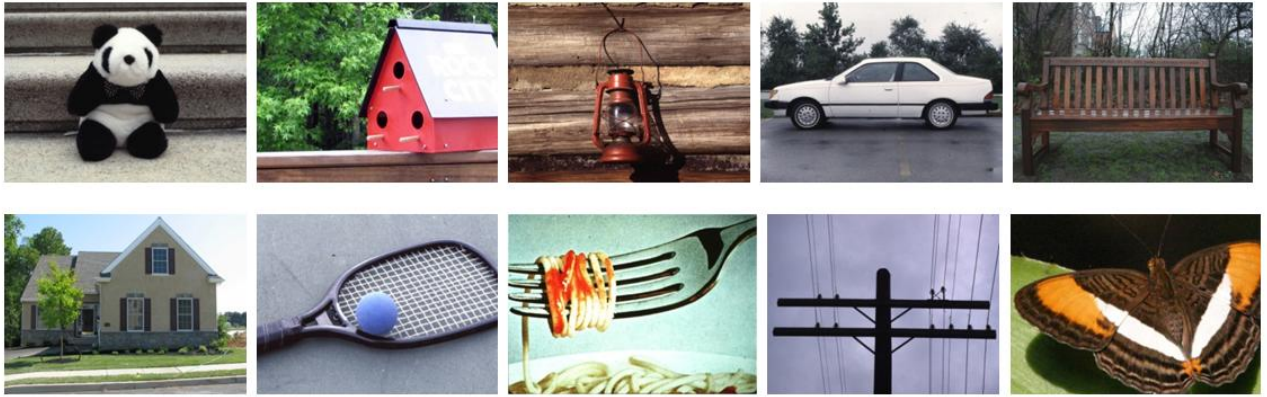
408 **Fig.1.**



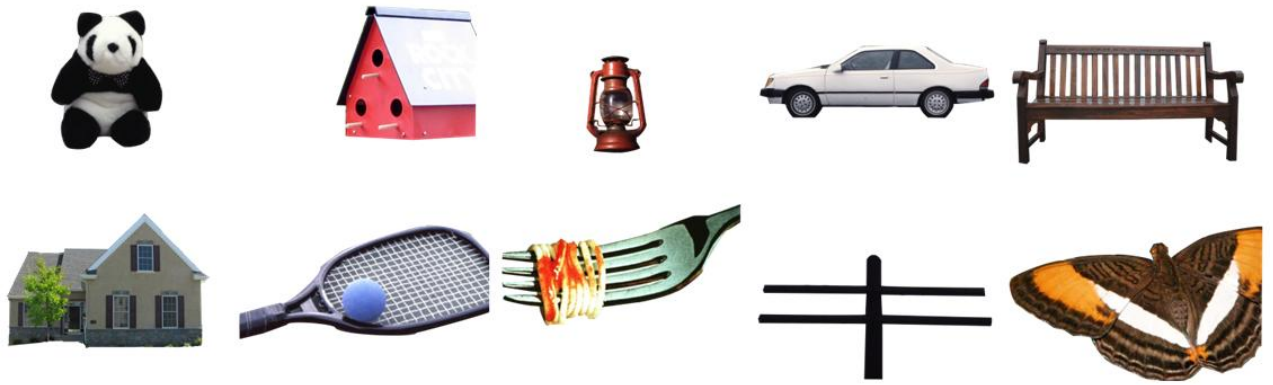
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419 Fig.2.

A



B



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422 **Fig.3**

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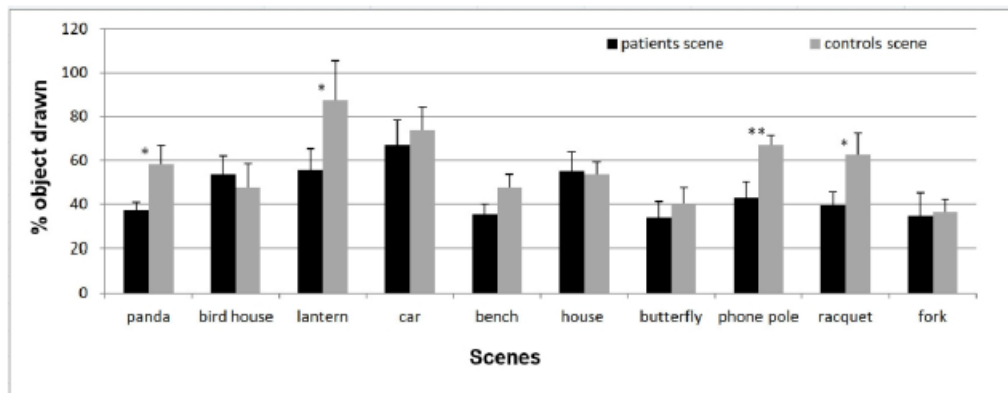


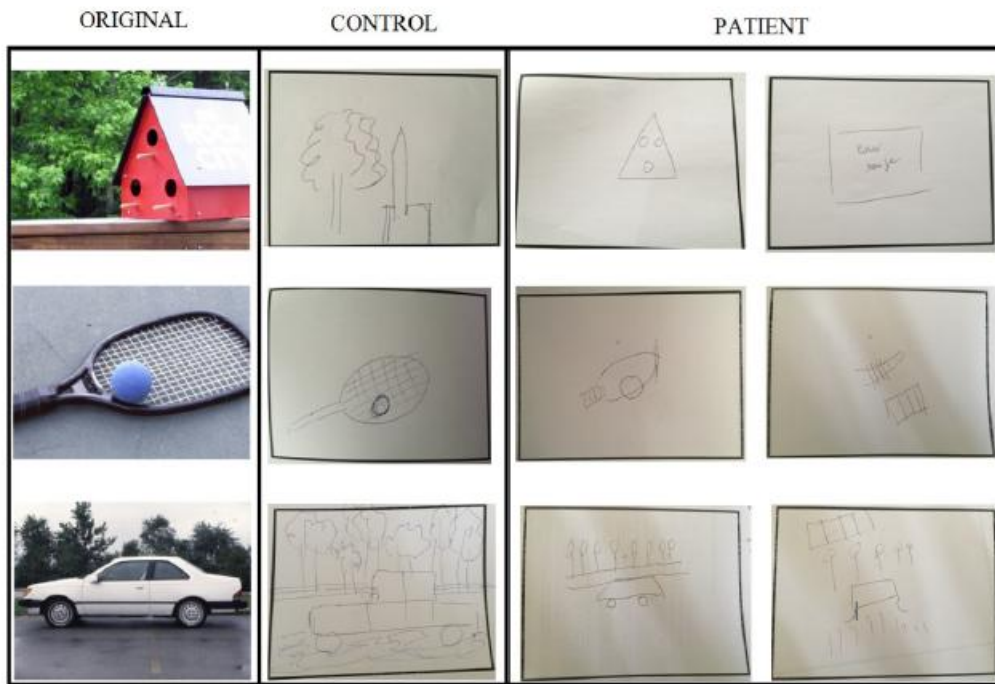
Figure 3. The boundary extension, in terms of percent object drawn (see formula in the result section) and the standard errors (*= p<.05, **= p<.02) as a function of the image used in the Scene Drawing Experiment and the group (patients vs controls).

140x54mm (300 x 300 DPI)

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426 **Fig.4.**



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Figure 4. Examples of drawings from control participants and from patients with glaucoma.

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429 **Fig.5.**

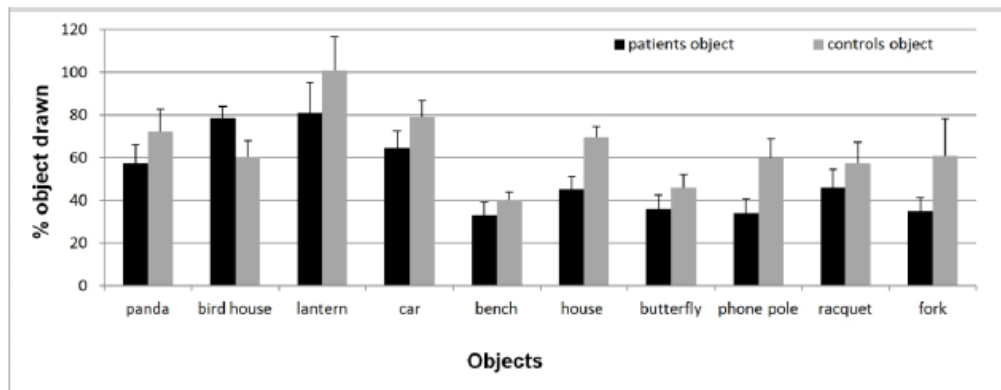


Figure 5. Comparison of the boundary extension for the Object Drawing Experiment, in terms of percent object drawn (see formula in the result section), and the standard errors, as a function of the image and the group (patients vs controls).

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